Discussion: Global Extraction of the Universal Dipole Amplitude from an Unbiased Initial Condition

Wenbin Zhao

Central China Normal University

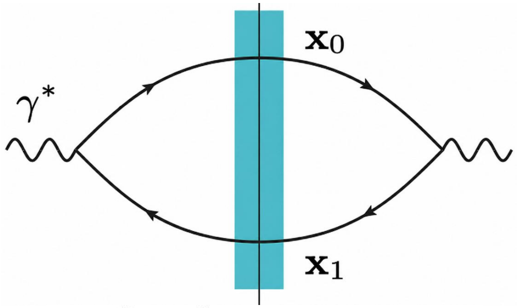
First small-x Workshop at the LHC in China

2026.07.09

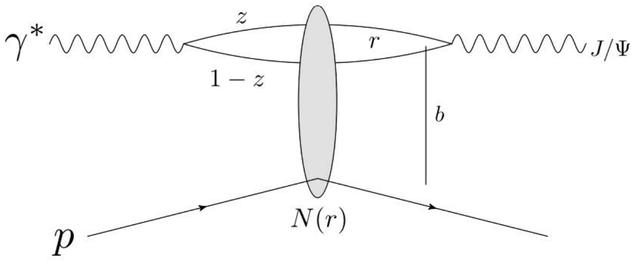
S. W. Dai, F. P. Li, L. G. Pang, G. Y. Qin, S. Y. Wei, H. Z. Zhang and W. Zhao, arXiv:2603.08008, and in progress

The dipole amplitude is available: https://doi.org/10.5281/zenodo.18826120

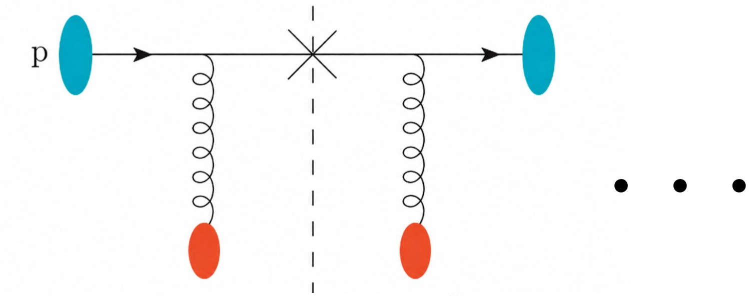
Universal Dipole Amplitude



$\sigma_{L,T}^{\gamma^* p \to \gamma^* p} \propto N(x, r_T, b)$



$\sigma_{L,T}^{\gamma^* p \to V p} \propto N(x, r_T, b)$



$\sigma^{pp \to h+X} \propto S(x, k_T)$ $\quad S(k_T, Y) = \int d^2\mathbf{r} e^{i\mathbf{k}_T \cdot \mathbf{r}} \left[1 - N(r, Y)\right].$

$$\frac{d\sigma^{pA \to hX}}{d^2p_\perp \, dy} = \frac{1}{(2\pi)^2} \int_{x_F}^{1} \frac{dz}{z^2} \left[\sum_q x_1 q(x_1, \mu^2) \, \tilde{S}_F\left(\frac{p_\perp}{z}, x_2\right) D_{h/q}(z, \mu^2) \right.$$

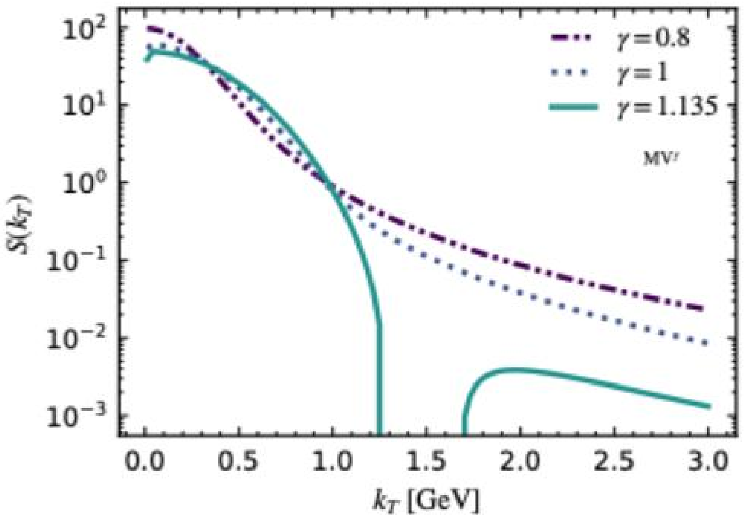
$$\left. + \, x_1 g(x_1, \mu^2) \, \tilde{S}_A\left(\frac{p_\perp}{z}, x_2\right) D_{h/g}(z, \mu^2) \right]$$

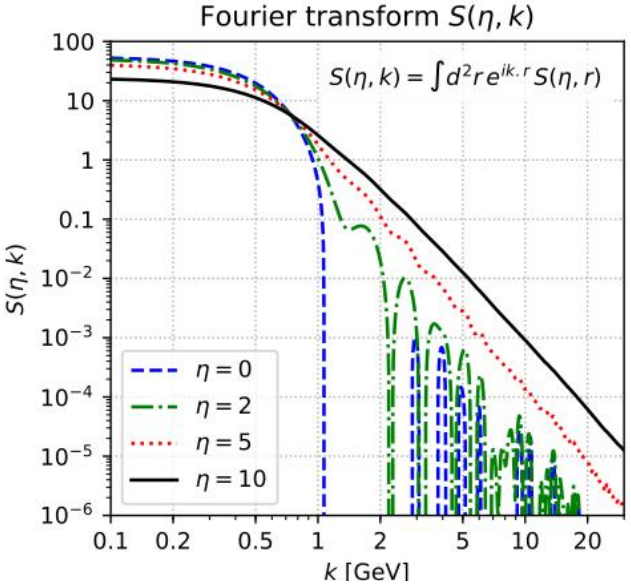
- The small-x dipole amplitude is **universal** across several processes.
- The dipole amplitude should be **positive** in both coordinate and momentum space.

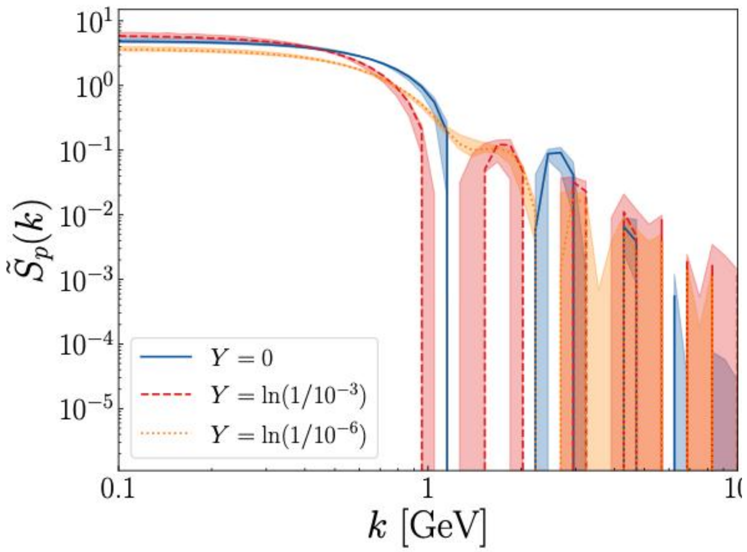
F. Dominguez, C. Marquet, B. W. Xiao and F. Yuan, Phys. Rev. D 83, 105005 (2011); Phys. Rev. Lett. 106, 022301 (2011).

G. A. Chirilli, B. W. Xiao and F. Yuan, Phys. Rev. D 86, 054005 (2012); Phys. Rev. Lett. 108, 122301 (2012).

Problem for ~ 20 Years







$$S(k_T,Y)=\int d^2\mathbf{r}e^{i\mathbf{k}_T\cdot\mathbf{r}}\left[1-N(r,Y)\right].$$

- Using MV-type parametrization, no one can fit the ep data while keeping the S(kT) positive.

References	χ^2/d.o.f. (σ_r^{total})	χ^2/d.o.f. ($\sigma_r^{c\bar{c}}$)	χ^2/d.o.f. (J/ψ)	$S(k_T)>0$?	Universal N?
Albacete *et al.* [Albacete:2010sy] (LO BK + LO Impact Factor)	~ 1.1	~ 1.3	N/A	No	No
B. Ducloué *et al.* [Ducloue:2019jmy] (ciBK + LO Impact Factor)	~ 1.0	N/A	N/A	No	No
Casuga *et al.* [Casuga:2025etc] (KCBK + NLO Impact Factor, Bayesian)	~ 1.2	~ 2.7	N/A	No	Yes
Casuga *et al.* [Casuga:2026xxt] (NLO+NLL BK + NLO Impact Factor, Bayesian)	~ 1.2	~ 2.4	N/A	No	Yes
This work, without "$S(k_T)>0$" constraint (ciBK + LO Impact Factor, PINN)	0.868	1.160	0.691	No	Yes
This work, with "$S(k_T)>0$" constraint (ciBK + LO Impact Factor, PINN)	**1.48**	**1.56**	**1.13**	**Yes**	**Yes**

AAMQS: EPJC, 771 (2011), 1705;
B. Duclouw, E. Iancu, G. Soyez and D. N. Triantafyllopoulos,PLB 803 (2020), 135305
C. Casuga, H. Hanninen and H. Mantysaari, PRD 112 (2025), 034003;

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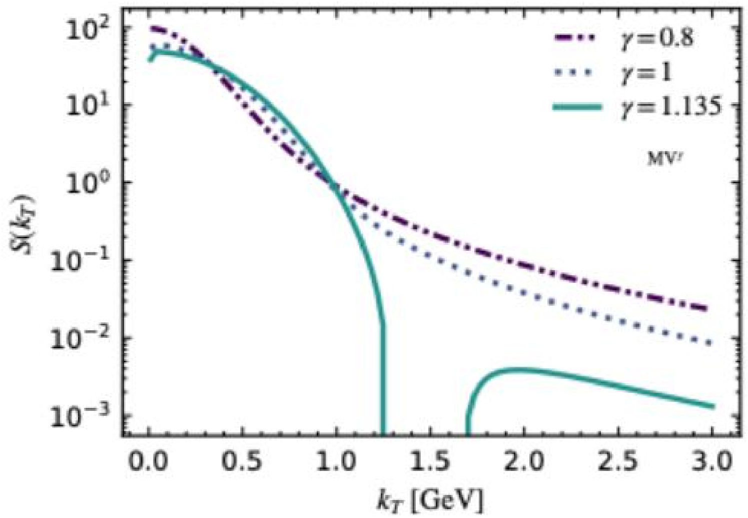

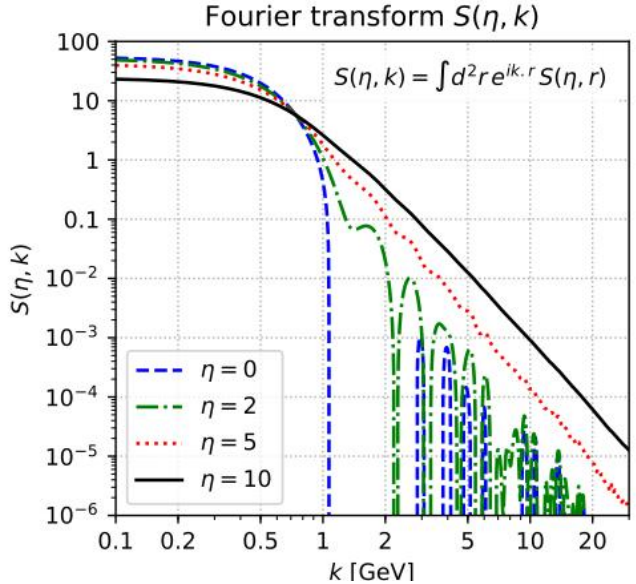

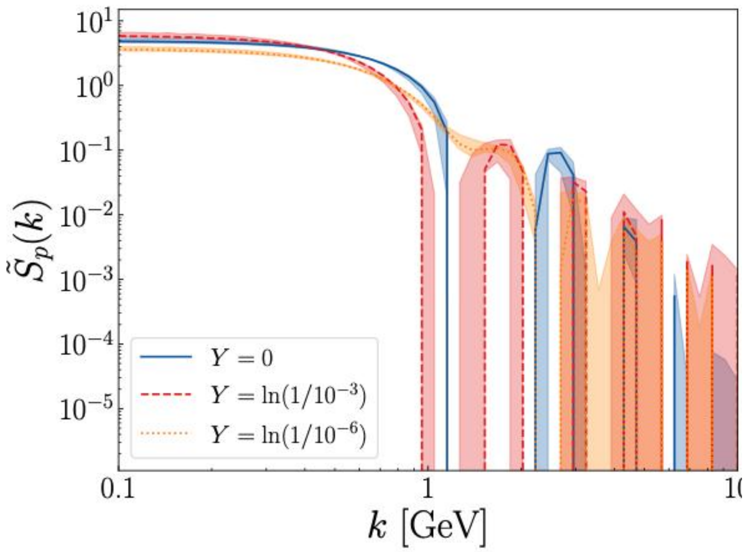

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Physics-Informed Global Extraction of the Universal Dipole Amplitude

Loss function in the PINN $$\mathcal{L}(\theta, \mathbf{p}) = w_1 \mathcal{L}_{\text{ciBK}} + w_2 \mathcal{L}_{\text{data}} + w_3 \mathcal{L}_{\text{phy}},$$

for ciBK evolution | quantifies agreement with data | additional physical constraints

Extract **Universal, Unbiased** Dipole Amplitude

- PINN extracts an **universal** amplitude constrained by the collinear improves BK.
- **Without imposing** a priori MV-type parametrization of the initial condition.

S. W. Dai, F. P. Li, L. G. Pang, G. Y. Qin, S. Y. Wei, H. Z. Zhang and W. Zhao, arXiv:2603.08008.

The dipole amplitude is available: https://doi.org/10.5281/zenodo.18826120

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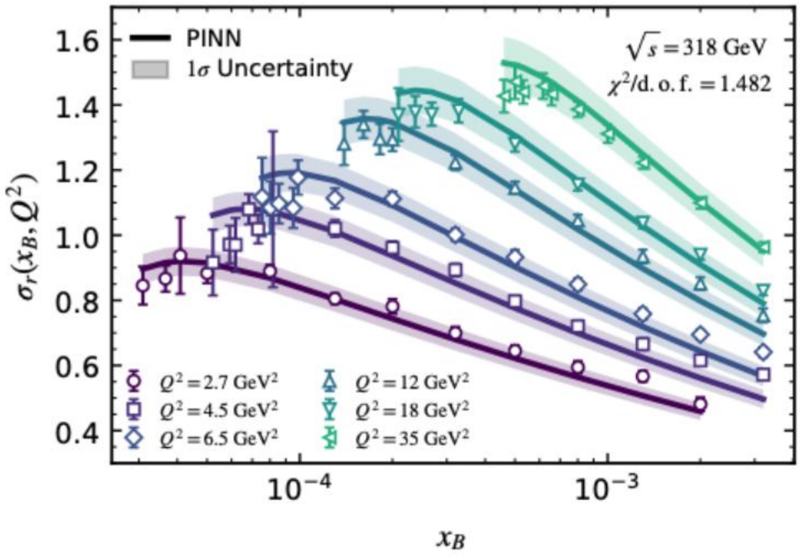

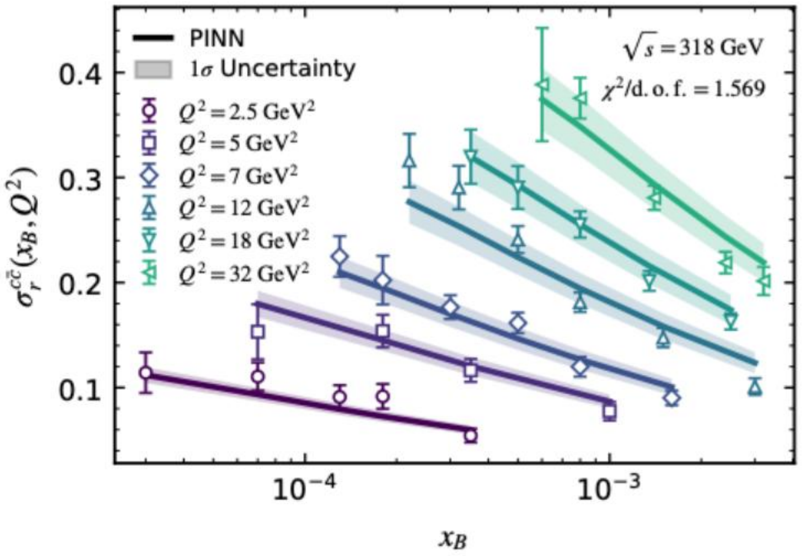

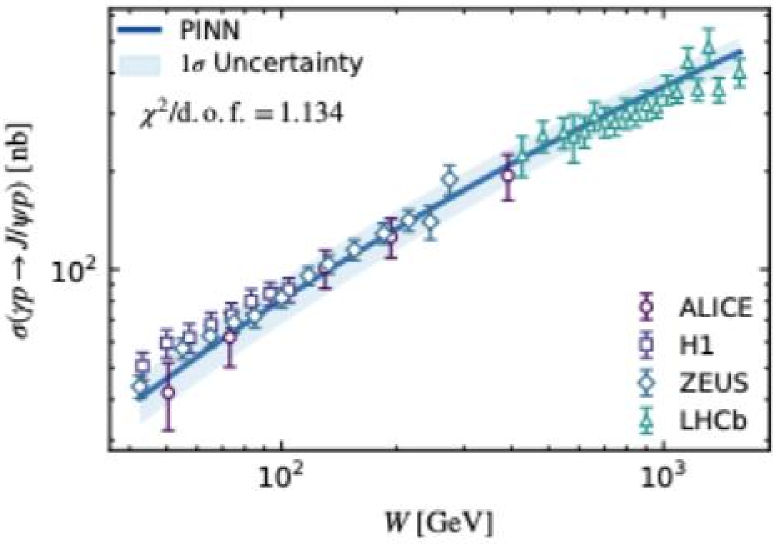

- PINN extracts an **universal** amplitude constrained by the BK.
- **Simultaneously** constrained by reduced **total** and **charm quark** DIS cross sections, exclusive **J/ψ data.**

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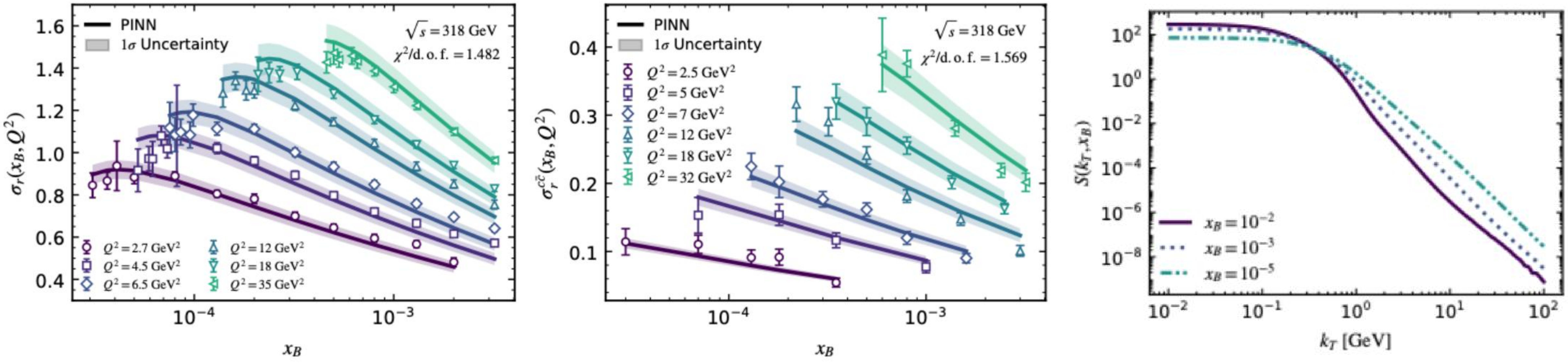
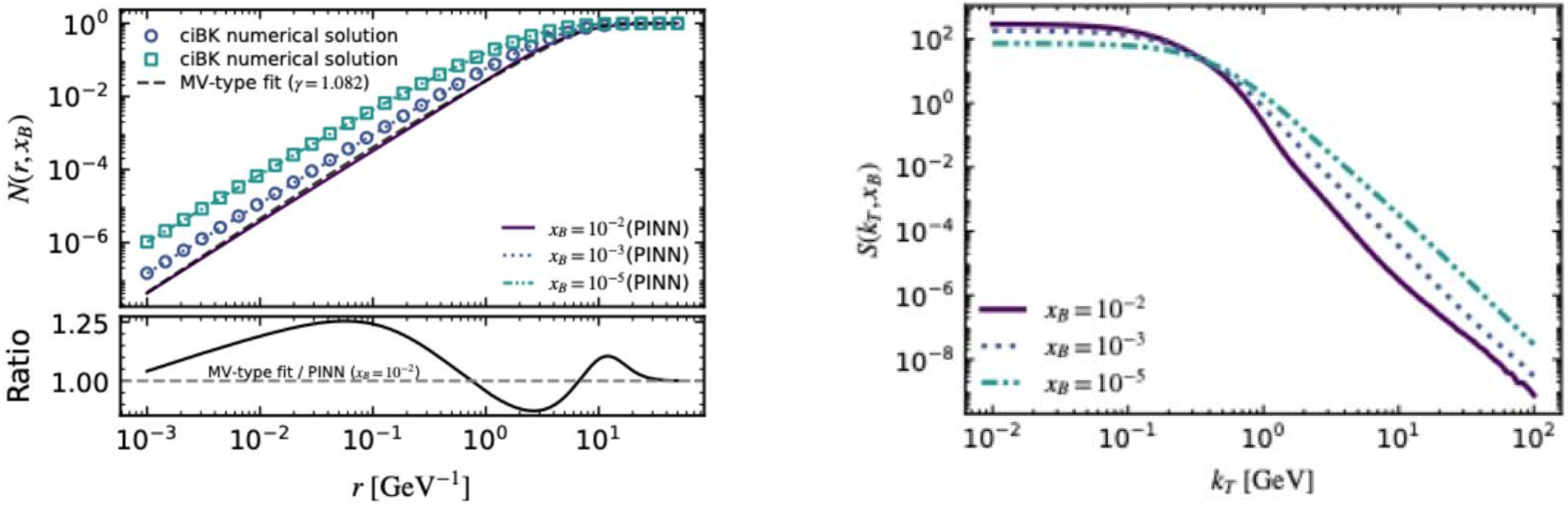


- PINN extracts an **universal** amplitude constrained by the BK.
- **Simultaneously** constrained by reduced **total** and **charm quark** DIS cross sections, exclusive **J/ψ data.**
- Keep the **positivity for the momentum-space amplitude.**

S. W. Dai, F. P. Li, L. G. Pang, G. Y. Qin, S. Y. Wei, H. Z. Zhang and W. Zhao, arXiv:2603.08008.

The dipole amplitude is available: https://doi.org/10.5281/zenodo.18826120

Dipole Amplitude of Proton

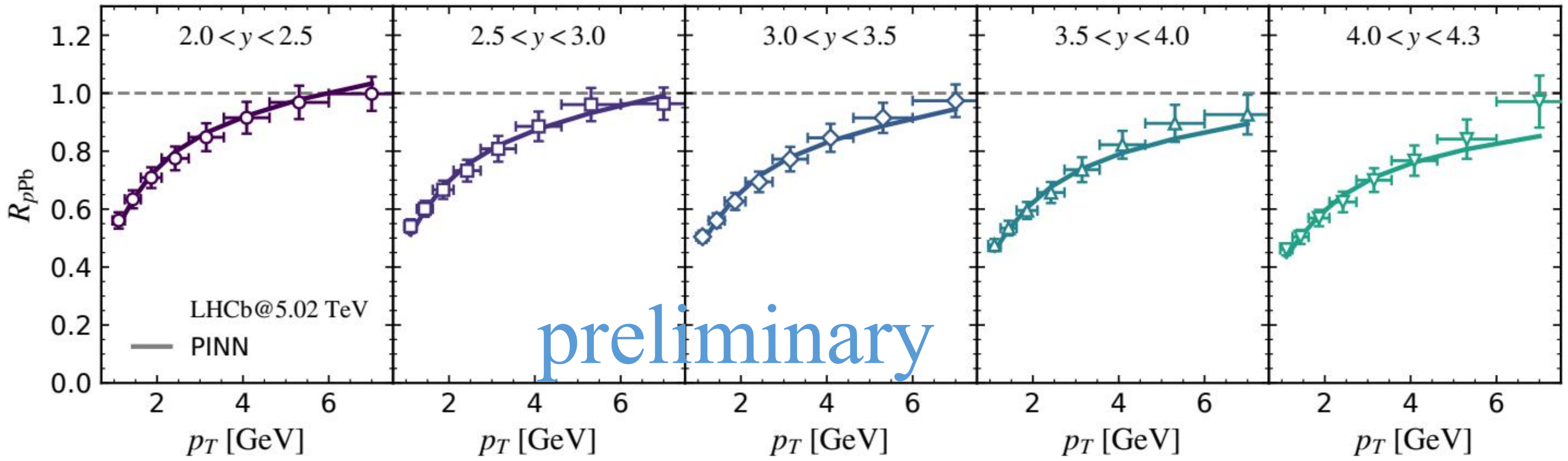


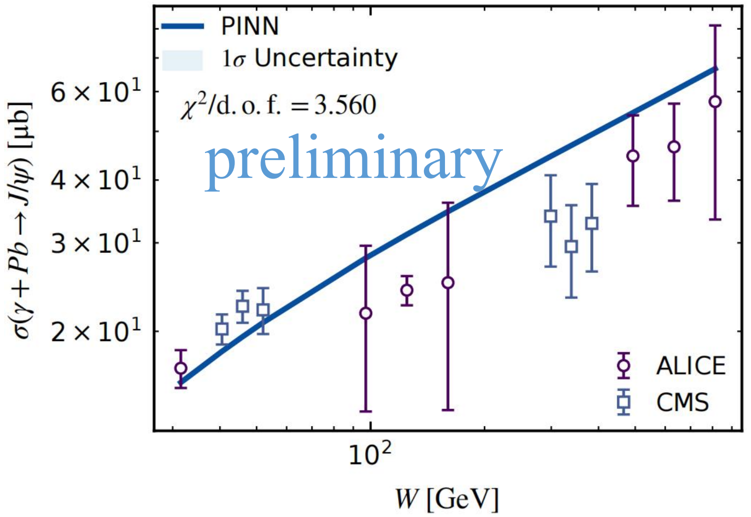
- To solve this problem, which has persisted for 20 years, we need to **go beyond** the MV parametrization.

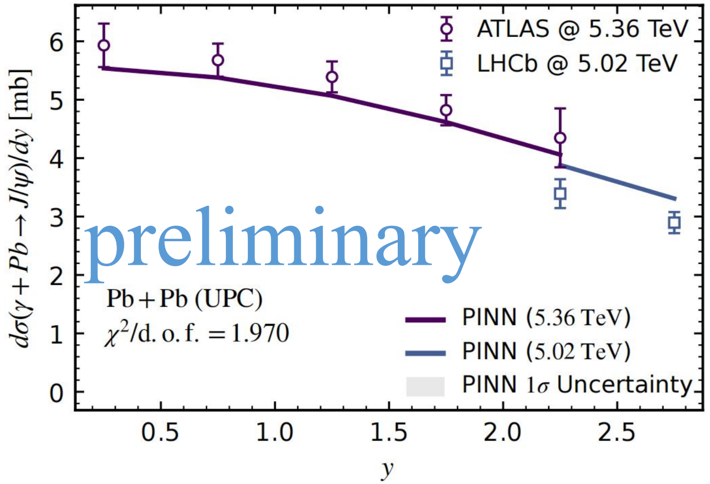
S. W. Dai, F. P. Li, L. G. Pang, G. Y. Qin, S. Y. Wei, H. Z. Zhang and W. Zhao, arXiv:2603.08008.

The dipole amplitude is available: https://doi.org/10.5281/zenodo.18826120

Global Extraction of the Nuclear Dipole Amplitude







- RpPb greatly **suppresses the uncertainty** from the FF and PDF.
- Every parameter **plays two roles**.
- There is some **tension** between the RpPb and J/ψ data. (EMD correction for J/ψ data?)

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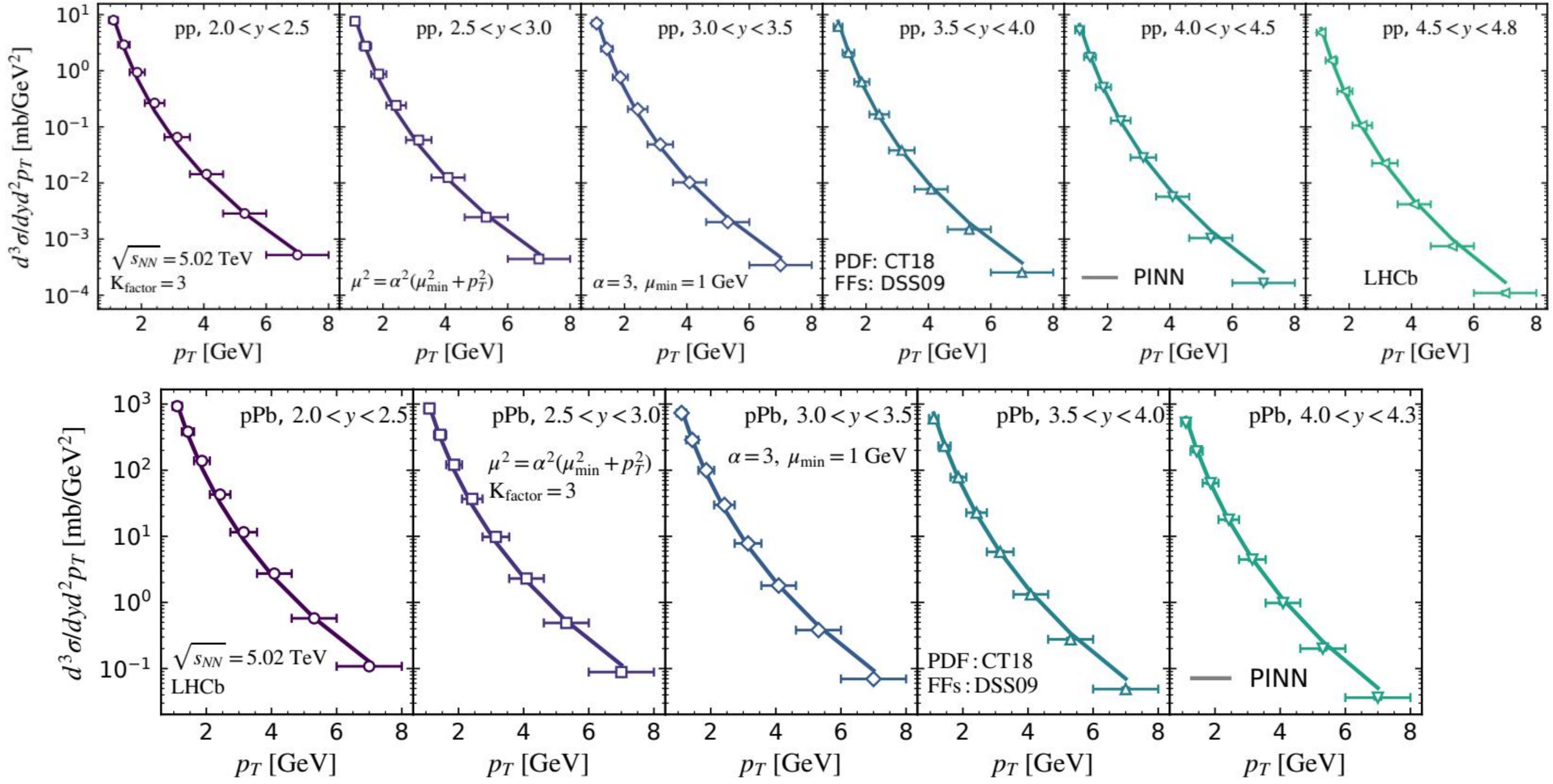
The dipole amplitude is available: https://doi.org/10.5281/zenodo.18826120

pT-spectra for pp and pPb



S. W. Dai, F. P. Li, L. G. Pang, G. Y. Qin, S. Y. Wei, H. Z. Zhang and W. Zhao, arXiv:2603.08008 and in progress.

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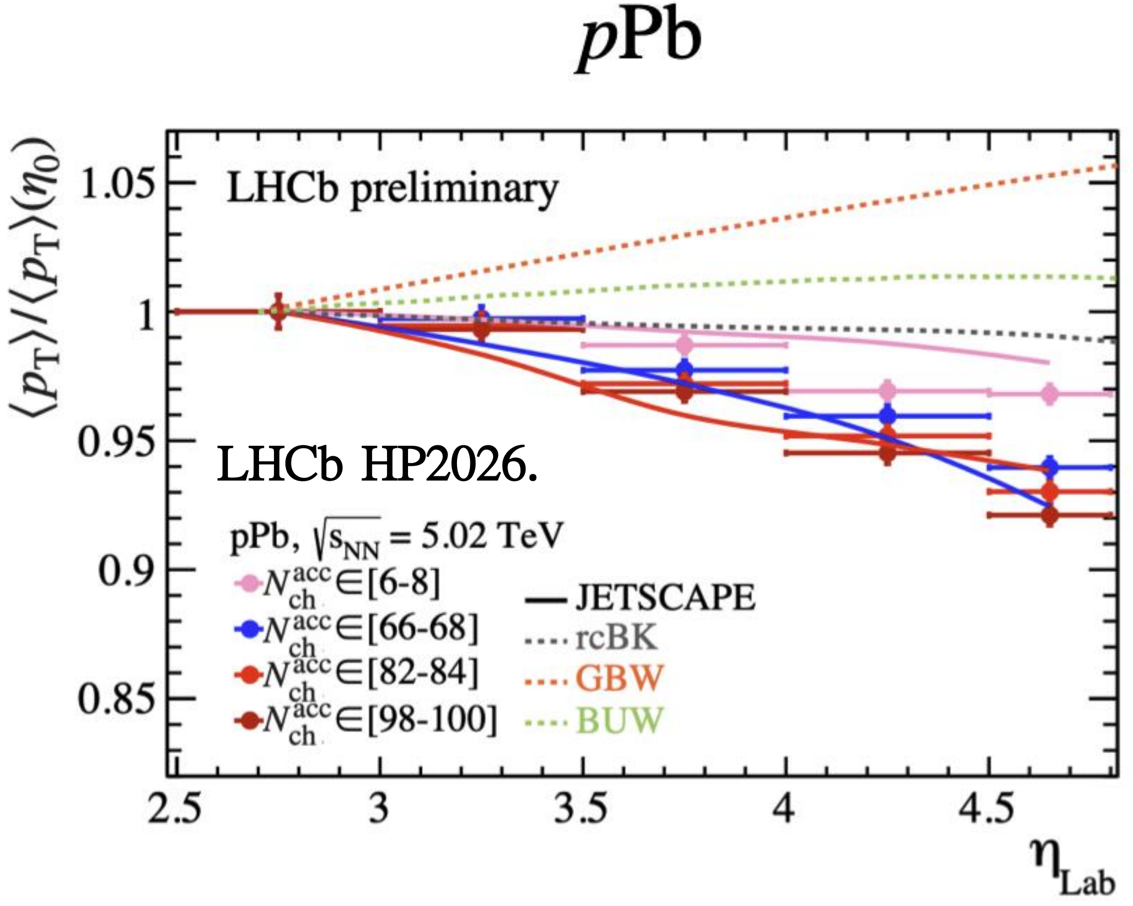
Mean p_T ratio v.s. η



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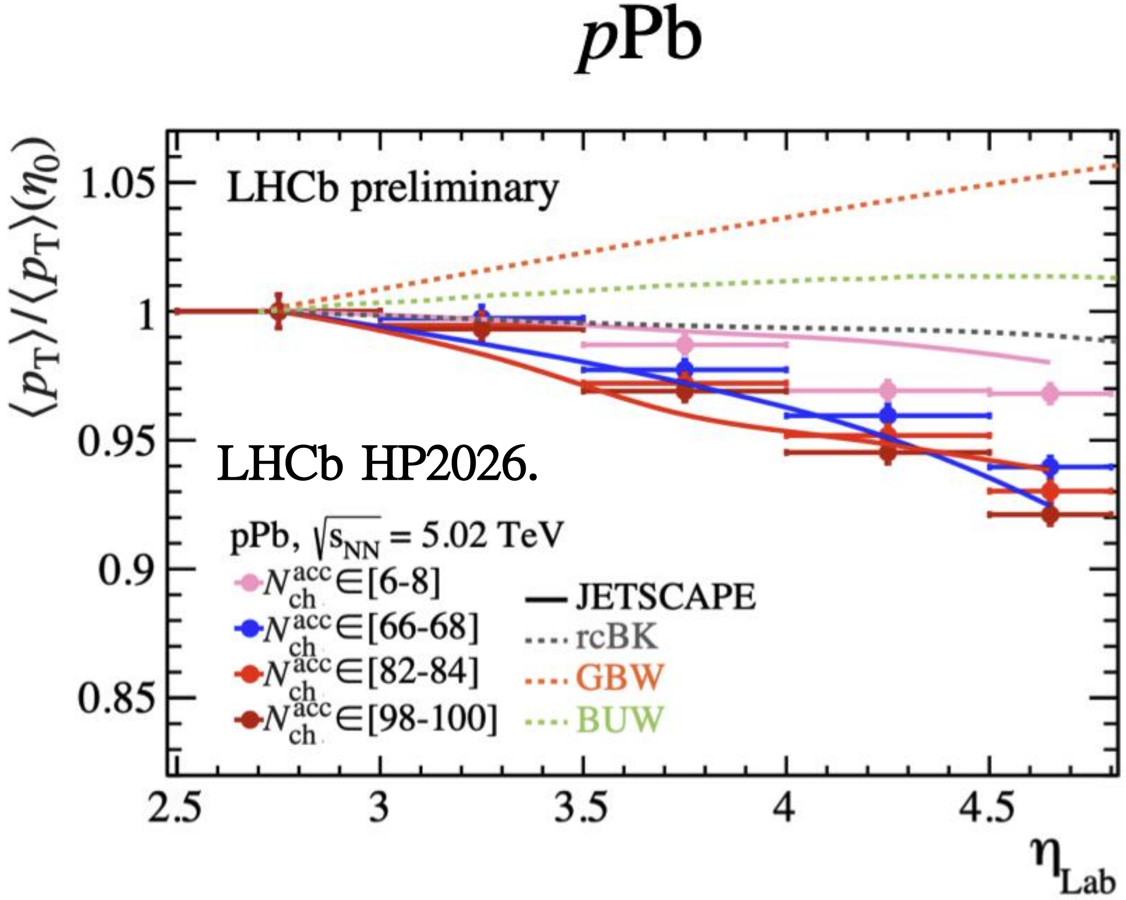

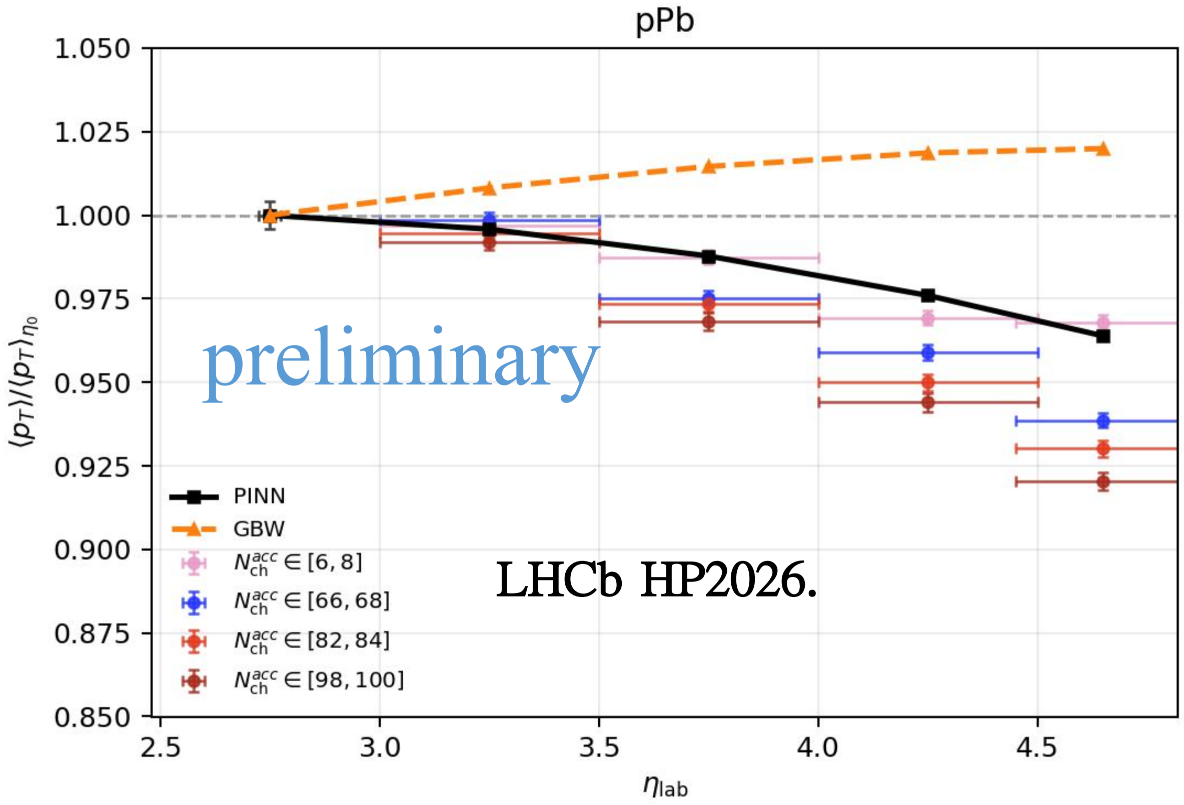

- Our CGC calculation of Mean p_T ratio v.s. η is **consistent** with the LHCb measurments at low Nch.
- In pPb, high Nch implies hydrodynamic behavior, while **low Nch results in CGC dominance.**

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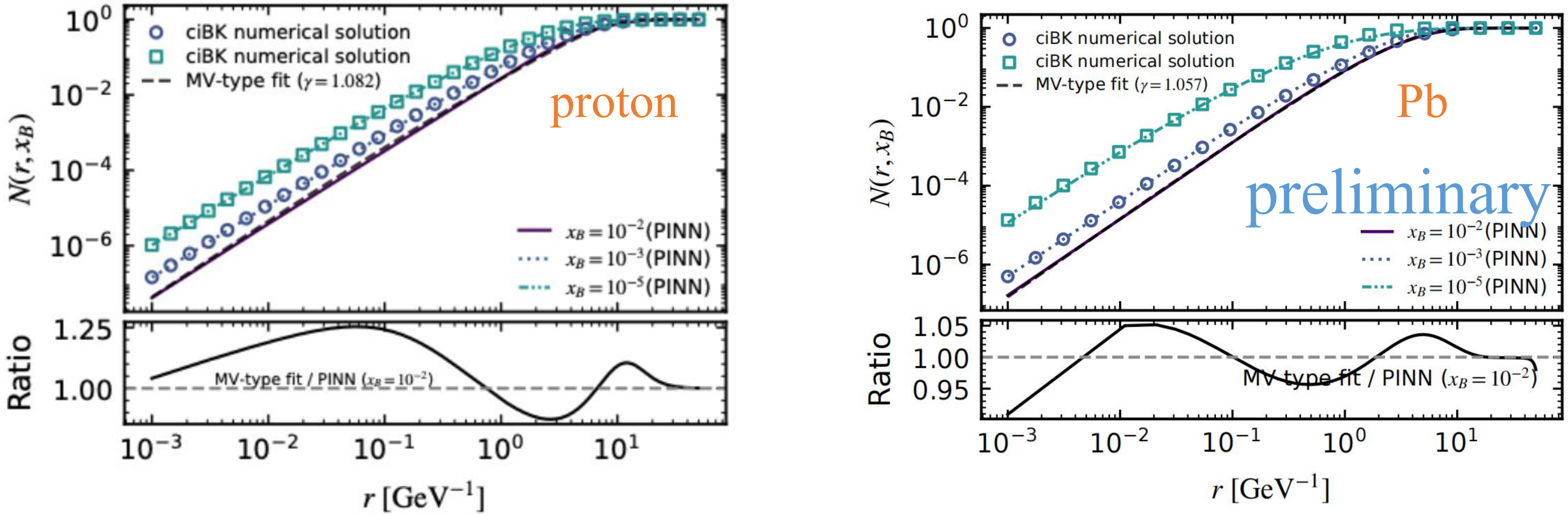
Dipole Amplitude of Pb



- The MV-type fit works better for Pb than for proton. (**MV model is designed for large nuclei.**)

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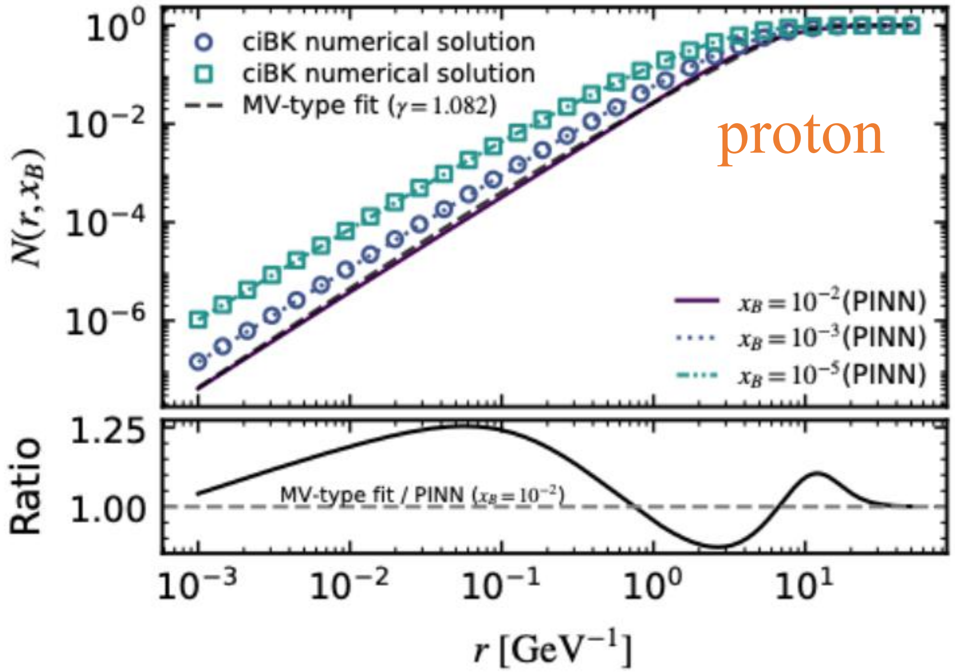

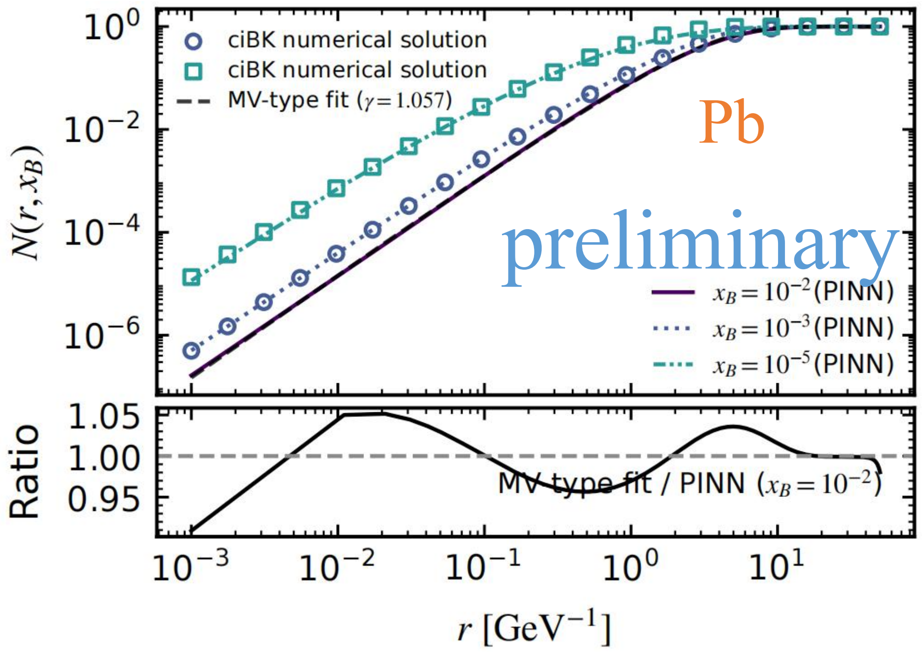

- The MV-type fit works better for Pb than for proton. (**MV model is designed for large nuclei.)**
- From the **unbiased** global fit, we obtain a ratio of $\frac{Q^2_{s0,Pb}}{Q^2_{s0,p}} \sim 3.1$.

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Two-Week C3NT Program, March 08-19, 2027 in CCNU

C3NT Program: Connecting Theory to Collider Data in the Era of Precision Saturation Physics

Mar 8 – 19, 2027
Central China Normal University
Asia/Hong_Kong timezone

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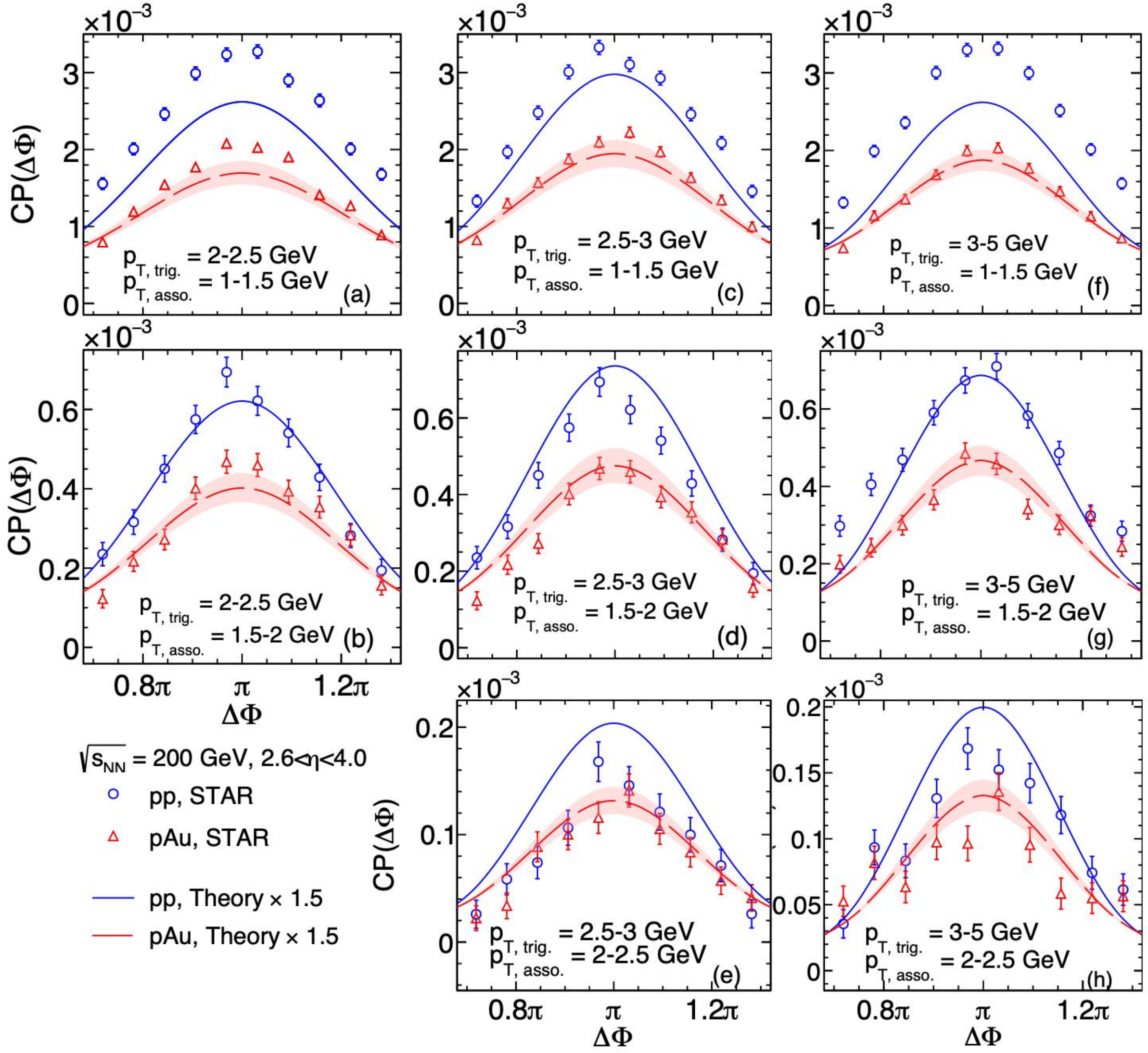
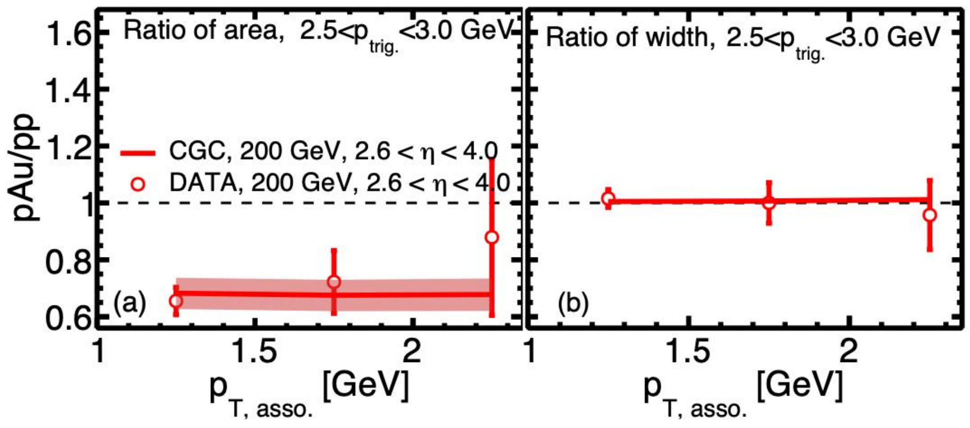
Dihadron Correlations in Forward collisions



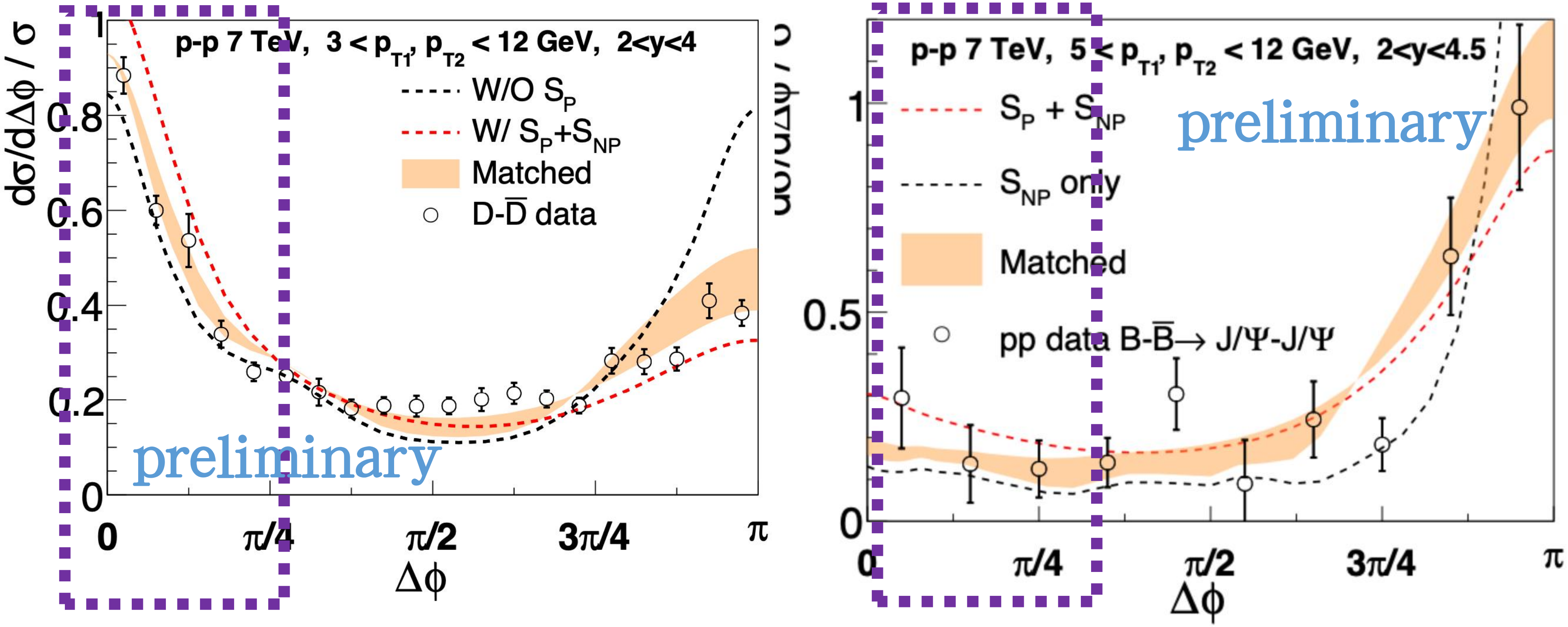
- Overall, it's good;
- Need an **additional normalization factor**. (There are uncertainties from FF).
- The first line is not well described.



- CGC predicts very **week p_T dependence**.
- The width ratio is very **close to 1, width is dominated by the Sudakov factor.**

P. Caucal, Z. B.Kang, P. Korcyl, F. Salazar, B. Schenke, T.Stebel, R.Venugopalan and W.Zhao, [arXiv:2512.21466].
STAR data: PhysRevLett.129.092501

Dihadron Correlations for Heavy Flavour

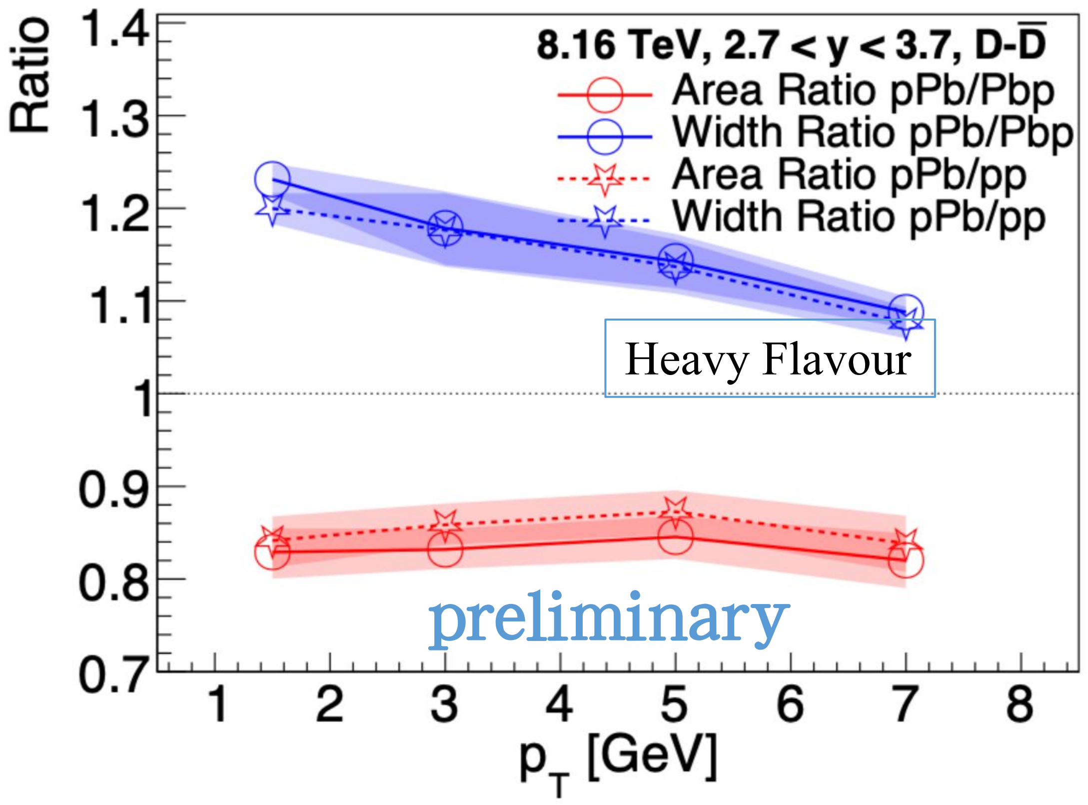


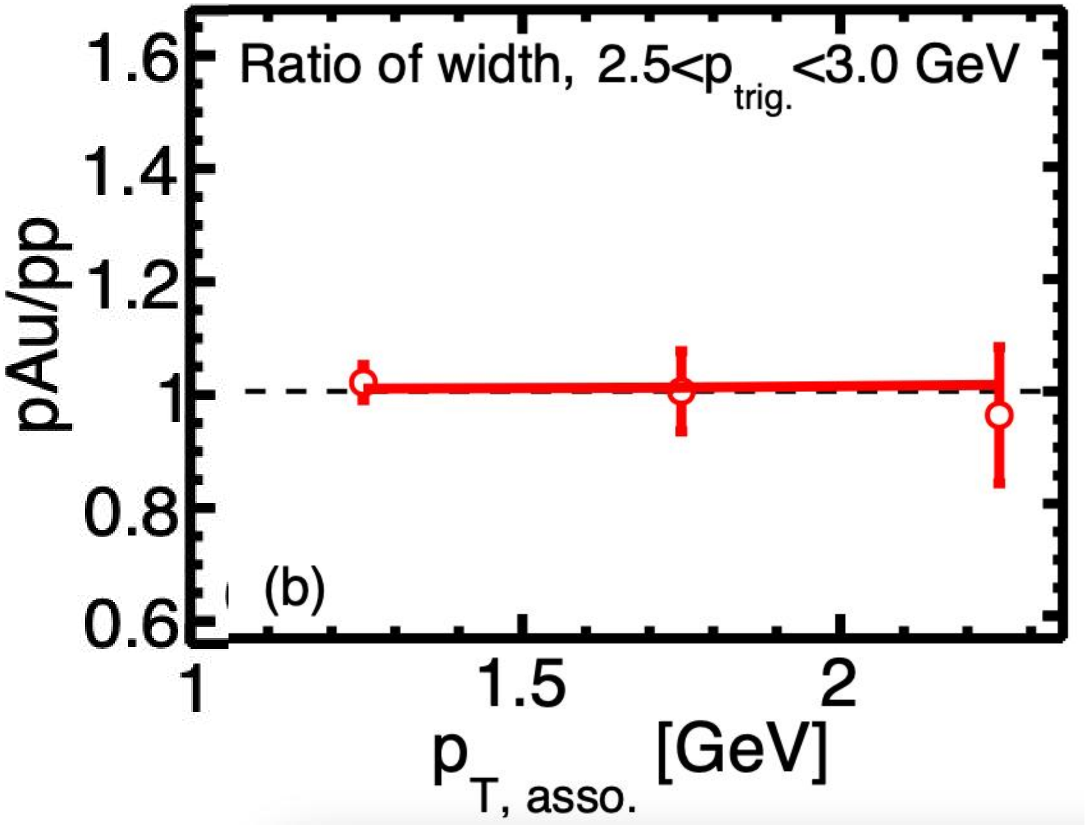
Matching Function: $G(R;c,n)=\frac{R^n}{R^n+c^{2n}}$, $R=\frac{Q^2}{k_T^2}$; with n = 5, band is from c= 1.5, 2.0, 3.0

- Well describe the B-B and D-D correlation in p-p with **Δ*φ* from to 0 to *π*.**
- Clean "**Dead Cone**" effects in B-B correlations.

W. Zhao, etc, al. in progross.

Area and Width Ratio between pPb, Pbp and p-p





- Width **ratio pPb/pp (or pPb/Pbp) >1.2** at 1-2 GeV bin, larger than light hadron.
- Npdf doesn't affect the width, but slightly decreases the area.

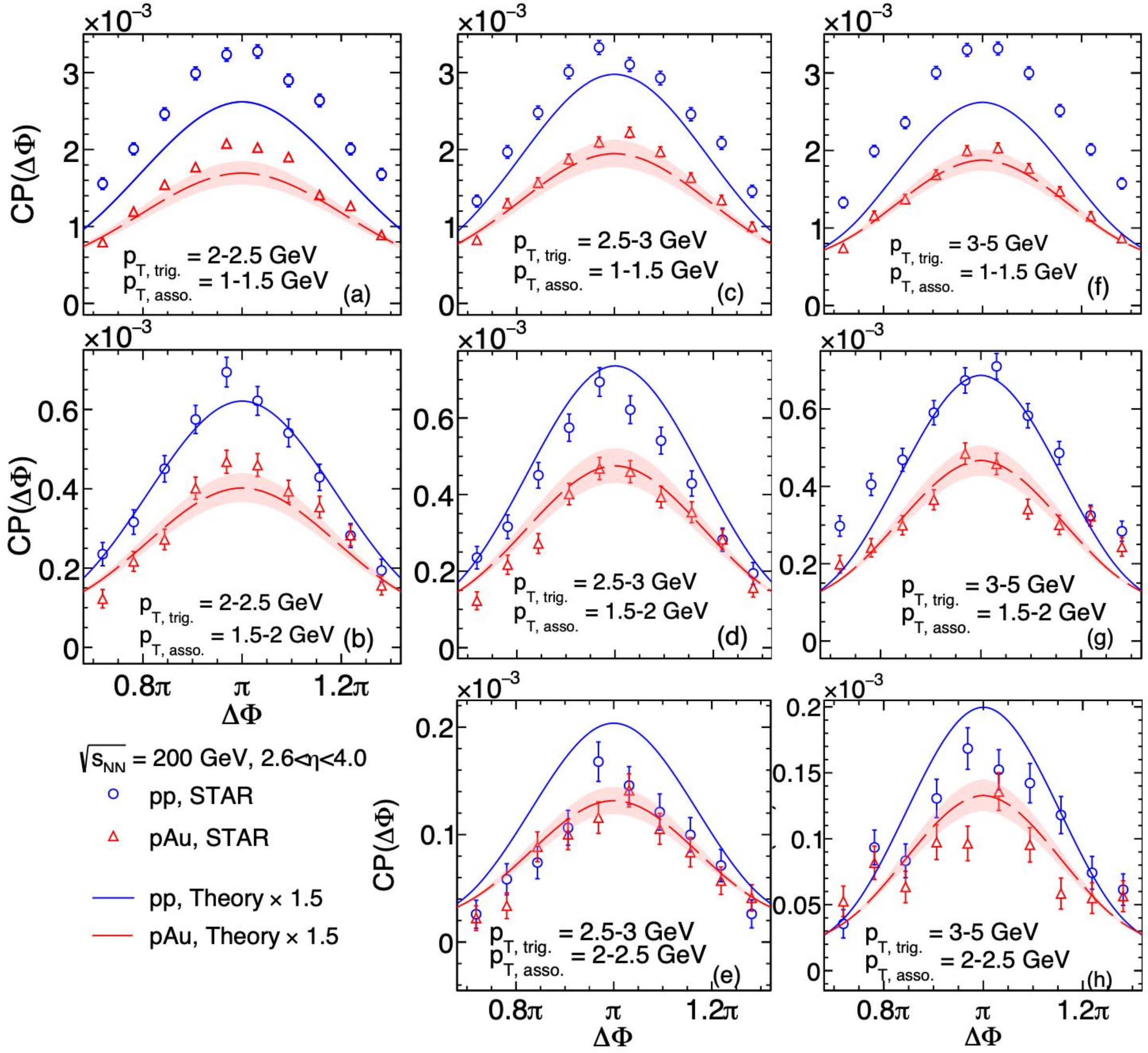
W. Zhao, etc, al. in progross.

Further thinking

- Higher Order calculations; Impact parameter dependence; Sub-eikonal; JIMWLK, BK, beyond mean field, large Nc,
- Speed up the simulations, Global fitting, Universal dipole constraint.
- Event generators, ISR, FSR, hadronization, Multi. fluctuations . Decouple Q^2 and small-x evolution?
- Di-hadron (jet), multi-hadron (jet) correlations. Diffractive productions. Heavy-flavor productions. TEEC.
- Color neutrality constrain for proton.
- Data, (J/Psi, EMD correction?)
- Nuclear size scan.
- Go to moderate x, H-T
- Neural Network, Quantum Computing.

Back Up

Dihadron Correlations in Forward collisions



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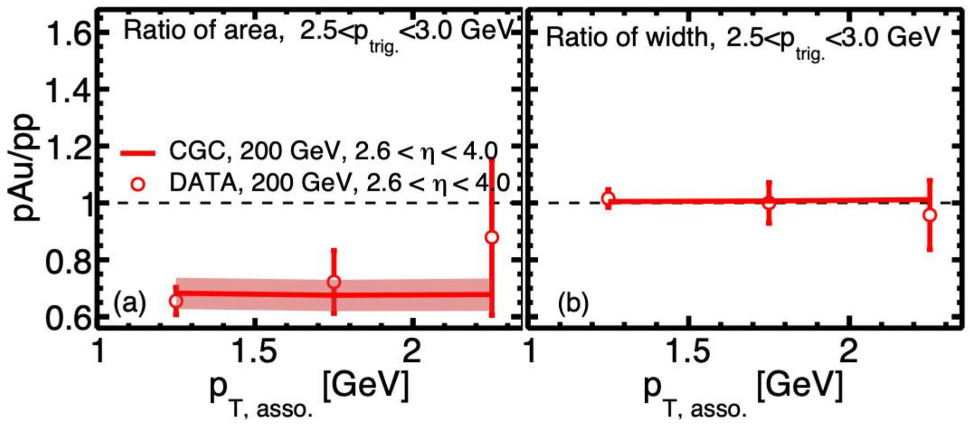

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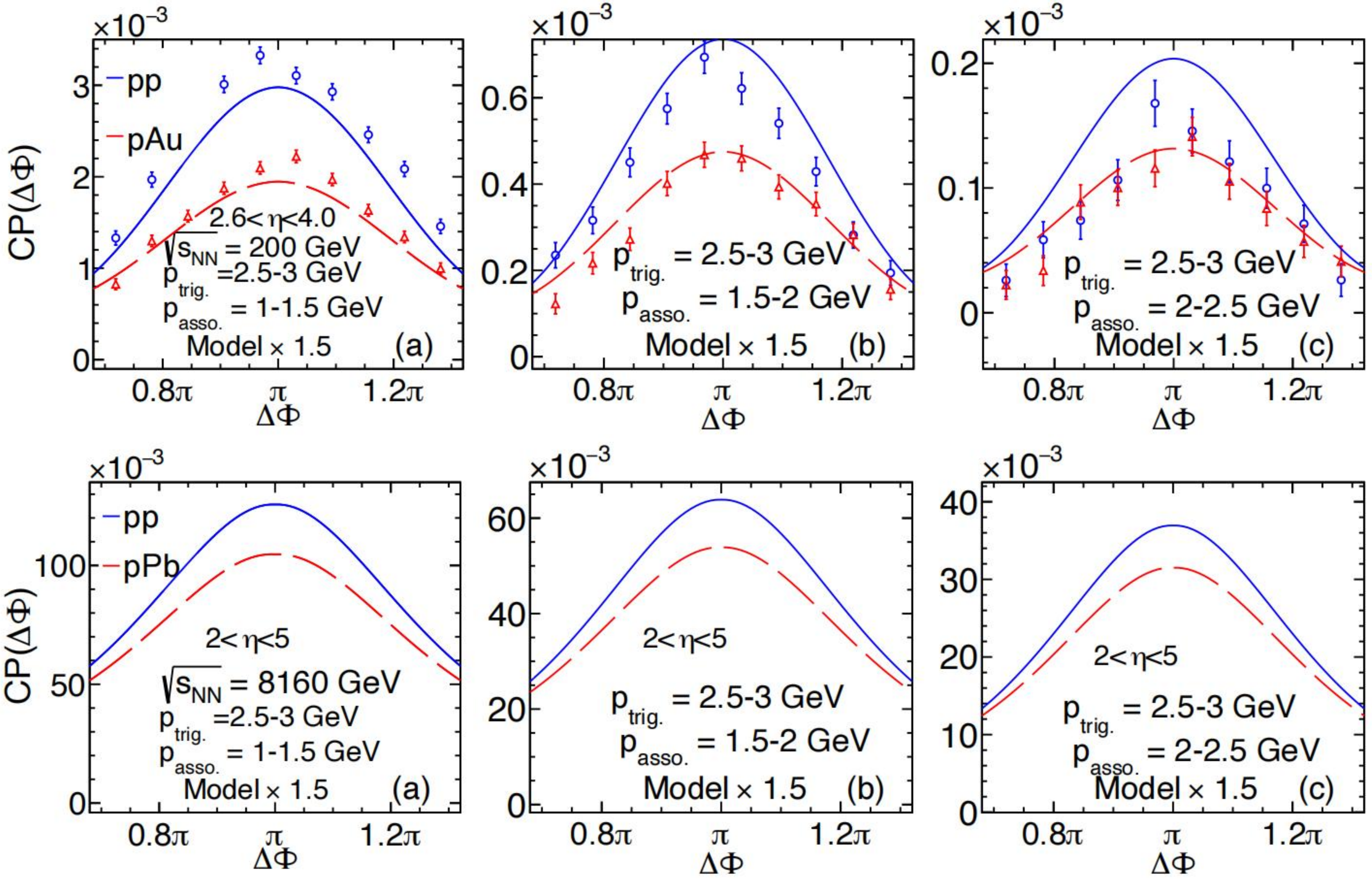
STAR data: PhysRevLett.129.092501

Dihadron Correlations in LHCb



STAR, 200 GeV
$2.6 < \eta < 4.0$

LHCb, 8.16 TeV
$2 < \eta < 5$

- Surprisingly, LHCb has the **smaller suppression** than STAR, even LHCb has smaller x_g .

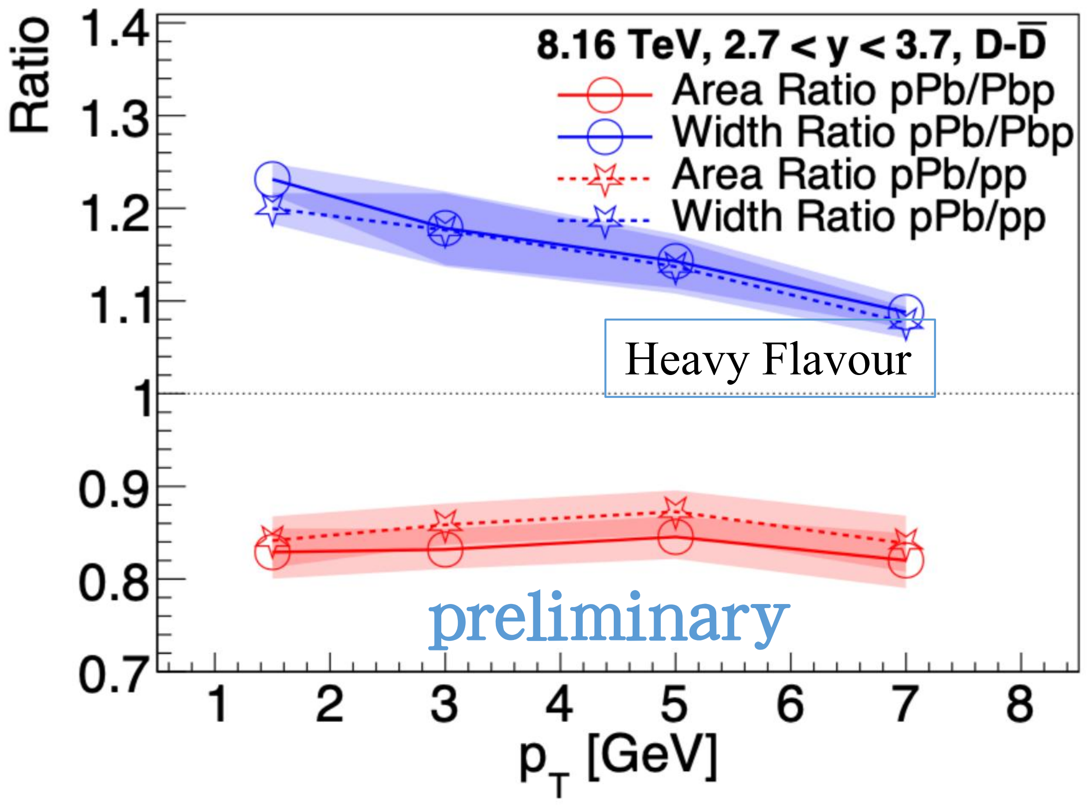
P. Caucal, Z. B.Kang, P. Korcyl, F. Salazar, B. Schenke, T.Stebel, R.Venugopalan and W.Zçhao, [arXiv:2512.21466].

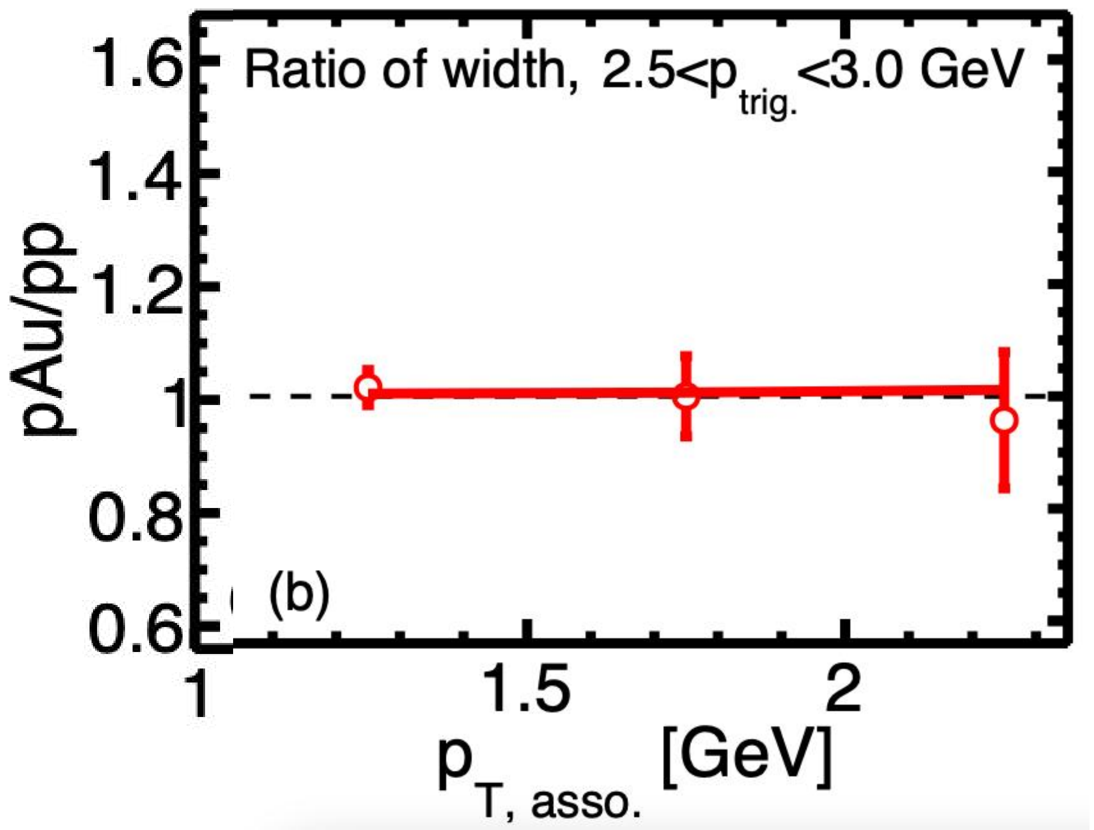
CiBK

$$\frac{\partial N(r,Y)}{\partial Y} = \frac{\bar{\alpha}_s(r^2)}{2\pi} \int d^2\mathbf{r}_1 \frac{r^2}{r_1^2 r_2^2} \left[\frac{r^2}{\min(r_1^2, r_2^2)}\right]^{\pm\bar{\alpha}_s A_1} \times \mathcal{K}_{\mathrm{DLA}}(\rho) \Big[N(r_1, Y-\delta_1) + N(r_2, Y-\delta_2) - N(r,Y) - N(r_1, Y-\delta_1) N(r_2, Y-\delta_2)\Big], \tag{1}$$

$$\mathcal{K}_{\mathrm{DLA}}(\rho) = \frac{J_1(2\sqrt{\bar{\alpha}_s \rho^2})}{\sqrt{\bar{\alpha}_s \rho^2}} = 1 - \frac{\bar{\alpha}_s \rho^2}{2} + \frac{(\bar{\alpha}_s \rho^2)^2}{12} + \cdots, \tag{3}$$

Area and Width Ratio between pPb, Pbp and p-p





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W. Zhao, etc, al. in progross.

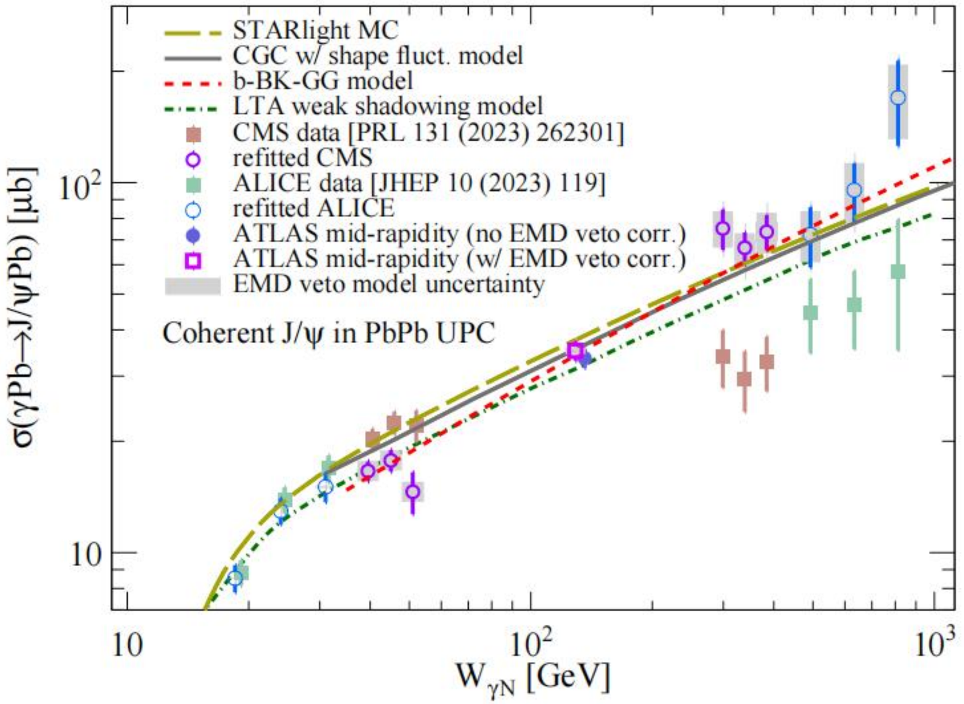
Corrections for Electromagnetic Ion Dissociation (EMD) in UPC

A First Account of the Impact of Ion Electromagnetic Dissociation on Event Exclusivity in Ultraperipheral LHC Collisions

M. Dyndal*
AGH University of Krakow, Faculty of Physics and Applied Computer Science, al. Mickiewicza 30, 30-059 Krakow, PL

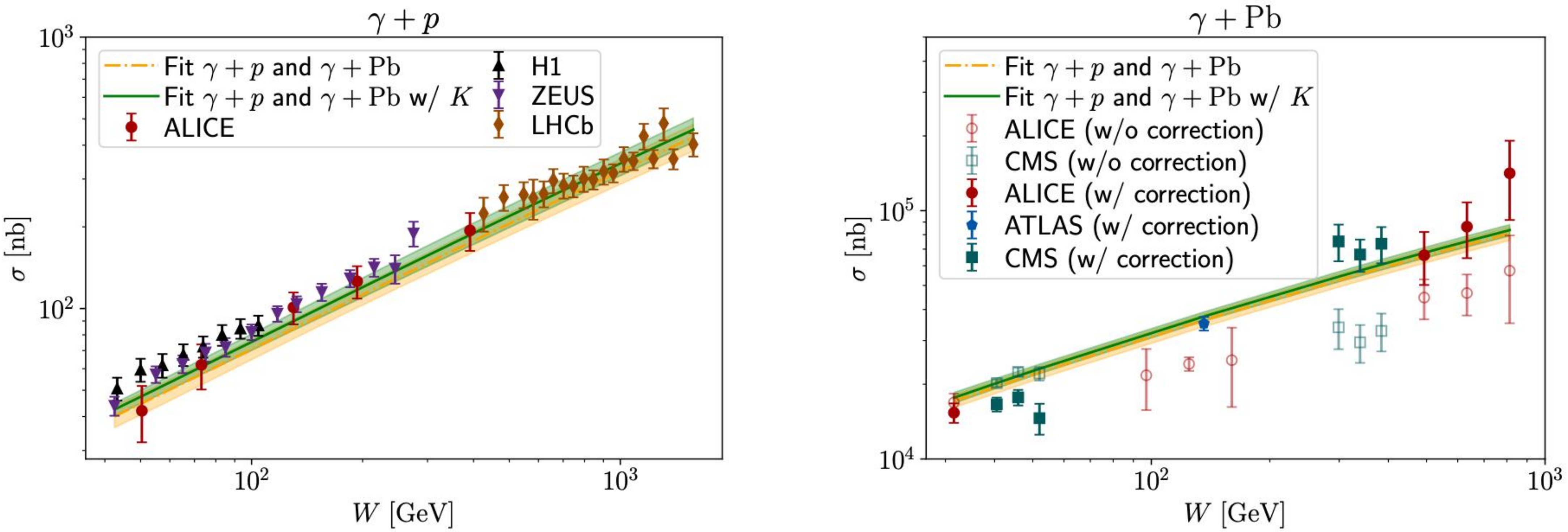
L. A. Harland-Lang†
Department of Physics and Astronomy, University College London, London, WC1E 6BT, UK

[M. Dyndal and L. A. Harland-Lang, [arXiv:2604.19879]].



- EMD occurs when photon excites the ion, which de-excites by emitting particles.
- It usually forward neutrons, but at high photon energies it produces mid-rapidity hadrons.
- It can trigger the experimental exclusivity veto and reduce the J/ψ photoproduction.

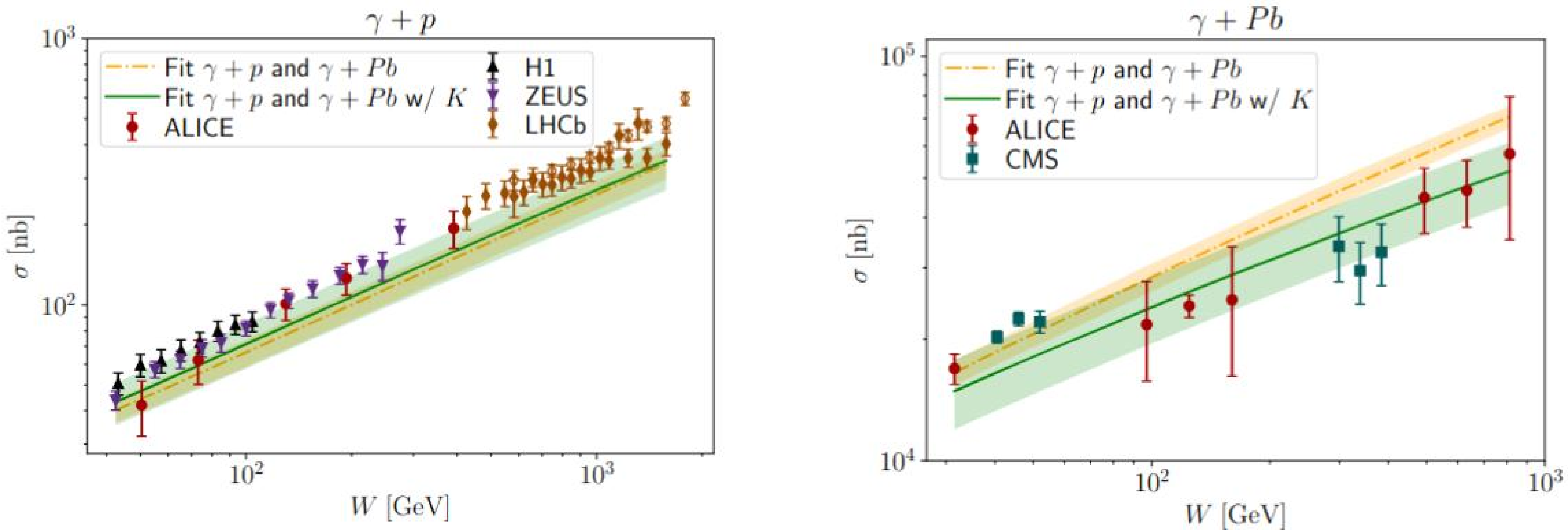
Revisiting the EMD-corrected J/ψ Production



H. Mantysaari, H. Roch, B. Schenke, C. Shen and W. Zhao, arXiv:2606.20362.

- The **tension** between the CGC model and the simultaneous description of the γp and EMC-corrected γPb data has **disappeared**.
- K~0.94 here for the green lines.

Global Bayesian analysis of J/ψ photoproduction on proton and Pb



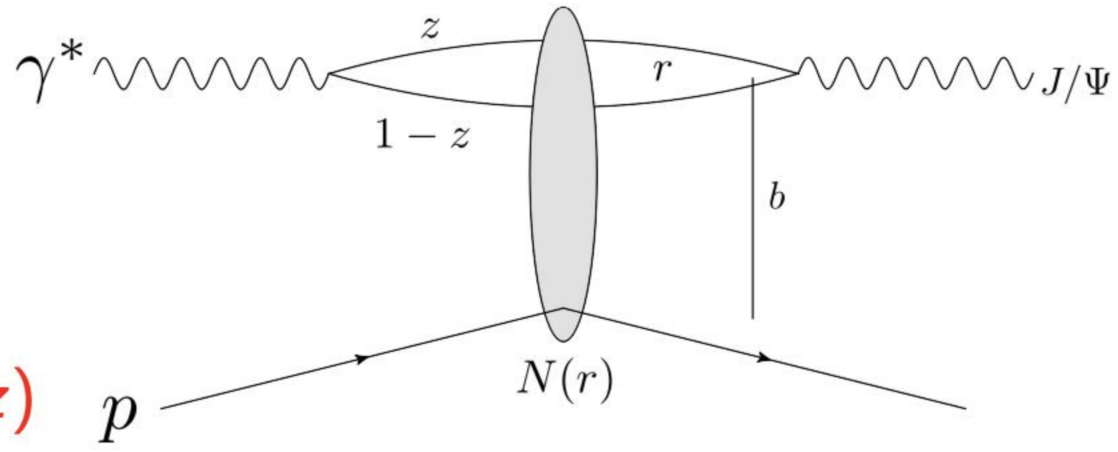
H. Mantysaari, H. Roch, F. Salazar, B. Schenke, C. Shen and W. Zhao, Phys. Rev. D 113 (2026), 014038.

- CGC model has **tension** to fit the γp and γPb data simultaneously. (See also: J. Penttala and C. Royon, PLB. 864, 139394 (2025).)
- K~0.3 here for the green lines.

Imaging nuclei with photon-nucleus reactions

High energy factorization:

1. $\gamma^* \to q\bar{q}$ splitting,
   wave function $\Psi^\gamma(r, Q^2, z)$
2. $q\bar{q}$ dipole scatters elastically N(r, x, b)
3. $q\bar{q} \to J/\Psi$, wave function $\Psi^V(r, Q^2, z)$



Diffractive scattering amplitude

$$\mathcal{A}^{\gamma^* p \to Vp} \sim \int \mathrm{d}^2 b \mathrm{d}z \mathrm{d}^2 r \Psi^{\gamma *} \Psi^V(r, z, Q^2) \mathbf{e}^{-\mathbf{ib}\cdot\mathbf{\Delta}} N(r, x, b)$$

Impact parameter, b, is the Fourier conjugate of the momentum transfer, $\Delta \approx \sqrt{-t}$,
N(r, x, b) dipole-target scattering amplitude.

$\boldsymbol{A}$ **~Fourier transform of the spatial structure function of target ($\boldsymbol{T_{p/A}}$).**

Miettinen, Pumplin, PRD 18, 1978; Caldwell, Kowalski, 0909.1254; Mäntysaari, Schenke, 1603.04349; Mäntysaari, 2001.10705